NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

AN ANALYSIS OF THE RELATIONSHIP OF FLIGHT HOURS AND NAVAL ROTARY WING AVIATION MISHAPS

by

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March 2017

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REPORT DOCUMENTATION PAGE				*Form Approved OMB No. 0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.				
1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** March 2017	**3. REPORT TYPE AND DATES COVERED** Master's thesis		
4. TITLE AND SUBTITLE AN ANALYSIS OF THE RELATIONSHIP OF FLIGHT HOURS AND NAVAL ROTARY WING AVIATION MISHAPS				**5. FUNDING NUMBERS**
6. AUTHOR(S) Damien Le				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000				**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A				**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB number ____N/A____.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.				**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

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The research uses individual and squadron-level, aggregate standardized daily, weekly, and monthly flight-hour data and employs a fixed-effects logit model. The research addressed errors and controls that could affect the outcome estimates. The model's individual estimates found enough evidence to support indicators used for sequestration, high flight hours, night flight, and overwater flight had statistically significant effects on the likelihood of a mishap at either the individual or squadron level. More research is suggested with modeling other aircraft platforms to better observe trends over time. The results provide policymakers with a better understanding of the relationship between the number of flight hours and its effect on mishaps. Policymakers can use that understanding to make more informed decisions about budgetary funding of naval aviation.

14. SUBJECT TERMS naval aviation, helicopter, pilot, causation, mishaps, flight hours, fatigue, likelihood of mishap, sequestration, Budget Control Act, night flight, overwater flight, naval rotary wing, aviation safety, NAVAIR, NAVSAFECEN, H-60 Seahawk			**15. NUMBER OF PAGES** 79
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540–01-280-5500 Standard form 298 (Rev. 2–89) Prescribed by ANSI Std. 239–18

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AN ANALYSIS OF THE RELATIONSHIP OF FLIGHT HOURS AND NAVAL ROTARY WING AVIATION MISHAPS

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
March 2017

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TABLE OF CONTENTS

LIST OF FIGURES

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LIST OF TABLES

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LIST OF ACRONYMS AND ABBREVIATIONS

A-G SFARP	Air-to Ground Strike Fighter Advanced Readiness Program
AGM	aviation ground mishap
AGM	aviation ground mishap
AMP	aviation master plan
ASUW	anti-surface warfare
ASW	anti-submarine warfare
BCA	Budget Control Act
CAS	close air support
CG	Guided missile cruisers
CNA	Center for Naval Analyses
CNAF	commander naval air forces
CNO	chief of naval operations
CO	commanding officer
COMHSCWINGPAC	commander, Helicopter Sea Combat Wing
CSAR	combat search and rescue
CSG	carrier strike group
CV	aircraft carrier
CVN	aircraft carrier, nuclear
DDG	guided missile destroyer
DECKPLATE	Decision Knowledge Programming for Logistics Analysis and Technical Evaluation (software)
DOD	Department of Defense
DON	Department of the Navy
DV	dummy variable
FAA	Federal Aviation Administration
FE	fixed-effects
FFG	guided missile frigate
FH	flight hours
FM	flight mishap
FMD	feet average missed distance

FRM	flight related mishap
FY	fiscal year
HAC	helicopter aircraft commander
HMAP	helicopter master plan
hrs	hours
HS	helicopter antisubmarine
HSC	helicopter sea combat
HSL	helicopter antisubmarine light
HSM	helicopter, strike maritime
HVBSS	helicopter visit board search and seizure
ISR	intelligence, surveillance, and reconnaissance
LAMPS	light airborne multipurpose system (helicopter)
LOG	logistics
LPM	linear probability model
NALCOMIS	Naval Aviation Logistics Command Management Information System
NAMI	Naval Aerospace Medicine Institute
NAS	naval air station
NATOPS	Naval Air Training and Operating Procedures Standardization
NAVAIR	Naval Air Systems Command
NAVSAFECEN	Naval Safety Center
NSW	naval special warfare
NVD	night vision device
OCO	overseas contingency operations
OPNAV	Office of the Chief of Naval Operations
OPNAVINST	Office of the Chief of Naval Operations Instruction
OPTEMPO	operating tempo
ORM	operational risk management
PII	personal identifiable information
POE	projected operational environment
RAC	risk assessment code

RBA	ready-based aircraft
ROC	required operational capacity
SAR	search and rescue
SSN	social security number
SQMD	squadron manpower document
T&R	training and readiness
TI	training interval
THD	tactical hard-deck
TMR	total mission requirement
T/M/S	type, model, and/or series
USMC	U.S. Marine Corp
VERTREP	vertical replenishment
VIF	variance inflation factor
WESS	web-enabled safety system

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EXECUTIVE SUMMARY

This research examined the relationship between aviation mishaps and the number of flight hours during periods of peak military funding (active conflict) and the period of sequestration starting in 2013. The research considered the issue of insufficient funding to sustain current readiness levels across the Department of Defense due to the Budget Control Act of 2011 and sequestration starting in 2013 as reasons for the investigation. Additionally, these cuts reduced the funding provision for squadron maintenance of aircraft. Squadrons operated at the flight hour's tactical hard-deck while in a stand-down phase with borderline funding for maintenance.

The main objective of this thesis is to create models to explore the relationship between the likelihood of mishaps due to periods of sequestration, night and overwater flight regime, fatigue (high hours), and proficiency (few hours). Specifically, the research examined the likelihood of a mishap at both the individual and squadron levels.

The Naval Safety Center and Naval Air Systems Command provided longitudinal (panel) flight hours and mishap data for fiscal years 2000 through 2016. Data was imported and coded in Stata (version 14) to create 17 models with different variances. The research was strictly limited to H-60 aircraft. These models are based on a fixed-effects logistic regression algorithm to determine inferences of likelihood estimation and to control for omitted variable bias. An aggregate standard deviation of the total number of flight hours was used based on previous one-seven and 30-day periods to create estimates for the likelihood of a mishap on a person or squadron. The models took two approaches to creating the estimates for high versus low flight hours on mishap estimations—a spline to estimate negative and positive standard deviation effects of flight hours, a high variable to examine flights in the 95th percentile, and a low variable at the bottom 10th percentile. The comparative models developed in the research explore whether too many or fewer flight hours affected the likelihood of a mishap. The research models include variables to account for the period of sequestration, indicators of lowered proficiency from too little flying and fatigue from too much flying, and certain flight conditions.

The results found statistically significant evidence to support that the total number of flight hours had an effect on the likelihood of a mishap at the individual or squadron-levels. The research found evidence in the period of sequestration, flight hours above the mean, high 95th percentile flight hours, night flight, and overwater. Specifically, sequestration had statistically significant effects only at the squadron level, while night flight had statistically significant effect only at the individual level. This suggests that natural conditions, which exist during nighttime flight, affect the performance of the individual and increases the likelihood of a mishap. The operations at night do not have an effect at the squadron level. Overwater flight had opposite effects at the squadron level versus the individual level. This opposite effect from the flight proficiency of a naval aviator naturally conditioned for overwater flying reduced the likelihood of mishaps compared to other aviators who did not fly over water and had a mishap. One unit increased in the standard deviation of flight hours the spline regression showed statistically significant effects on the increased likelihood of a mishap at the squadron level on a previous day. This indicates squadrons that operate higher than the mean hours on average are at greater risk to have a mishap.

Overall, the results provided strong evidence to support that the total number of flight hours had both positive and negative effects on the likelihood of a mishap at the individual and squadron levels. The results provide policymakers with a better understand of the relationship between the number of flight hours and its effect on mishaps. Policymakers can use that understanding to make better-informed decisions on budgetary funding to naval aviation.

ACKNOWLEDGMENTS

First, I would like to thank Dr. Jeremy Arkes for sharing his expertise, knowledge, undivided attention, and leadership throughout my research. I would also like to thank Professor Bill Hatch for his guidance, mentorship, and invaluable instruction in my journey here at NPS. Without their support and direction, I would not have the same level of success with the completion of this thesis.

I extend a personal thank you and offer my appreciation to Mr. Edward Hobbs from the Naval Safety Center and to Mr. Christian Hawes from Naval Air Systems Command for providing the data for conducting my research. Their help was instrumental in the creation of this thesis.

Lastly, I want to thank my wife, Cuc Pham, for taking care of our daughter, Olivia, while I was away during long nights at the library, for putting up with everything, and for supporting me through our chapter here in Monterey.

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I. INTRODUCTION

A. PURPOSE

This research aimed to examine the relationship between mishaps and the total number of flight hours in H-60 rotary wing naval aviation. The research considered the issue of insufficient funding to sustain current readiness levels across the Department of Defense (DOD) due to the Budget Control Act (BCA) of 2011 and sequestration starting in 2013, which are potential factors affecting aviators and increasing the likelihood for mishaps. Additionally, considerations include fatigue from too many flight hours and reduced levels of proficiency from too few flight hours. The comparative models developed in this research explore whether too many or too few flight hours affected the likelihood of a mishap. The research models include variables to account for certain conditions of flight, sequestration, lowered proficiency from too little flying and high levels of fatigue from too much flying.

The research is limited to only the H-60 series naval rotary aircraft. The author's research serves only for professional development and is strictly informational in nature. It is not sponsored by any DOD organization or sub entities. The models for this research do not forecast mishap probability but analyze historical data from fiscal years (FYs) 2000–2016.

B. BACKGROUND

The United States economy had a historic recession in 2008. This resulted in unprecedented nationwide federal and state budget cuts over the following years, leading to the BCA of 2011 and sequestration starting in 2013. Those budget constraints directly affected naval aviation. Sequestration established a decremental reduction in spending and an across-the-board budget cut, which led to a reduction in flight hours throughout naval aviation. Those budget cuts also decreased the funding provision for maintenance of the squadron aircraft. As a result, squadrons that were in a stand-down phase were only funded to operate at tactical hard-deck (THD), or the absolute minimum number of flight hours to maintain a required level of readiness in the aircraft. Commanders

struggled to meet training requirements to maintain the required readiness levels with fewer funded flight hours under the new policy. Their challenge was to find the balance between maintaining proficiency levels for aviators and meeting training requirements for combat readiness. This type of budget shift could affect an aviator's performance and could increase the likelihood of a mishap.

This budget shift potentially endangers the safety of the pilots supporting the warfighting efforts. Under such conditions, squadrons are forced to operate at THD with the same readiness requirement. In addition, operational readiness requires an aviator to safely and successfully complete a mission that requires meeting a number of conditions. The ability to successfully conduct a mission is derived from the pilot's proficiency in the mission tasks. Actual levels of proficiency were not a consideration with the THD policy. The total number of pilot flight hours is not a sufficient measure for proficiency. This is because proficiency varies between individuals; it is not established based on a numeric value. However, memory decay can contribute to lower levels of proficiency when there are too few hours flown within a given period.

This research examined the effects of high flight hours as an indicator for fatigue and low flight hours as an indicator for low levels of proficiency. Night flights and overwater controls were used to better estimate flight hours on the likelihood of a mishap. Additionally, controls for flights that occurred after March 1, 2013, were used to indicate the period of sequestration.

This chapter defines all H-60 rotary aircraft models included in the research. Additionally, the chapter introduces the background of variables selected for the models to provide an understanding of their relationship to flight hours and mishaps within this research. Finally, data for the research covers period of peak military funding (FY 2000—February 2013) to periods of sequester (March 2013—September 2016).

1. Sikorsky Legacy H-60 Seahawk

The H-60 is a multi-engine, multi-mission, all-weather rotary aircraft developed by Sikorsky for service in the U.S. military. Sikorsky received a contract from the U.S. Army in the 1960s to develop a multi-mission rotary-aircraft capable of fulfilling future

combat missions and to replace the aging Hue helicopter post-Vietnam. A decade later, the Navy sought a solution to its aging SH-2 helicopter in Sikorsky. Fond of the capabilities of the Army Blackhawk, the Navy contracted Sikorsky to reengineer a version of the Army H-60 that was capable of fulfilling seagoing operations. Sikorsky eventually developed multiple versions of the H-60 for use by the Navy.

The Seahawk became the Navy version of the Army H-60 platform and thus became SH-60 used by the U.S. Navy. The primary differences between the Army and Navy H-60s is that the Navy SH-60 has automatic blade folding capability, manual tail-pylon fold capability, and upgraded main struts to deal with landing on ships in rough seas. The different series of SH-60s consist of SH-60B, SH-60F, HH-60H, MH-60S, and MH-60R. All versions use the same H-60 platform, and the major differences are mission specific weapon configuration and an all glass cockpit in the later Sierra and Romeo versions.

The first version, the SH-60B Seahawk, acquired by the Navy in the early 1980s, was specifically designed to be a light airborne multipurpose system (LAMPS) Mark III for anti-submarine (ASW) and anti-surface warfare (ASUW) for use on U.S. Navy frigates (FFG), destroyers (DDG), and cruisers (CG). Although its primary mission was ASW, it served as the primary platform for at-sea search and rescue (SAR). Alternately, it performed intelligent surveillance and reporting (ISR), vertical replenishment (VERTREP) as well as troop transport. All squadrons using the SH-60B were designated as helicopter antisubmarine light (HSL) squadrons.

The second version, SH-60F, acquired by the Navy in 1988, was specifically designed to deploy in support of the carrier strike group (CSG) for ASW. The SH-60F utilized most of the weapon systems as the SH-60B. However, a radar system or electronic countermeasures, necessary for expeditionary type missions, are not installed in the SH-60F, so it relies on the support from the CSG for guidance. Additionally, without the weight of a radar system, the internal cabin is configured for SAR support of fixed winged aircraft launch and recovery operations on a carrier (CV). All squadrons using the SH-60F are designated as helicopter antisubmarine (HS) squadrons.

The third version, HH-60H, introduced in the early 1980s, is specifically designed to serve as a multipurpose overland and overwater platform for combat search and rescue (CSAR), naval special warfare (NSW), and ASUW. Additionally, it can be configured for VERTREP and logistics (LOG) missions. All HH-60H helicopters jointly operated with HS squadrons. Later in the 2000s, the U.S. Navy helicopter master plan (HMAP) set forth by the chief of naval operations (CNO), consolidated the HH-60H to two special operations squadrons (HSC-84 and HSC-85).

2. Modernized H-60 Seahawk

The HMAP, derived from the aviation master plan (AMP) and approved by the CNO, restructured rotary winged assets that consolidated the SH-60B and HS-60F into the MH-60R version. The MH-60R can operate on navy nuclear carriers (CVN), FFGs, DDGs, and CGs; however, its primary mission is overwater ASW and ASUW along with all secondary predecessor missions. In addition, the MH-60R absorbed all mission essential components of prior platforms as well as an ungraded glass cockpit for enhanced situation awareness. All squadrons previously using the SH-60S/F have been redesignated to helicopter, strike maritime (HSM) squadrons.

The HMAP additionally called for the consolidation of the UH-3H, CH-46D, HH-60H, and HH-1N naval helicopters into the MH-60S. The MH-60S’ primary missions are CSAR and NSW. Secondary missions include SAR, VERTREP, medical evacuation, ASW, helicopter visit board search and seizure (HVBSS), close air support (CAS), and ISR. In addition, two large cabin sliding doors and a single aft-mounted tail wheel for brownout-landing environments was mounted on the MH-60S. It is primarily designed to operate overland and on naval aircraft carriers. MH-60S squadrons are designated as helicopter sea combat squadrons (HSC). All H-60 models share the same platform but are unique in their individual abilities to perform different missions. Additionally, the equipment within each version plays a unique role on affecting the level of performance on which the aviator contributes to the mission.

3. Night and Overwater Flight Conditions

Although each version of the H-60s is designed to perform specific set of missions, they share two essential capabilities. The first is night covert operations under infrared lighting conditions or starlight reflectivity using night vision devices (NVD). The second is takeoff and landing from most U.S. military ships as well as some foreign military ships.

Operations at night or overwater are more taxing on the physical and physiological conditions of the aviator. Moreover, night flight requires extra levels of risk management due to the physiological nature of human circadian rhythm and reduced situational awareness from a lack of natural lighting. Overwater flight lacks physical cues from which closure rates can be determined. Additionally, the cyclical landing platform on the ship at sea is very challenging for a pilot. The combination of both night and overwater flight increases demands imposed on the aviator, which directly affect the likelihood of a mishap. The demands during these flight conditions induce a higher level of stress, which when compounded over time, ultimately leading to higher levels of fatigue. This research creates variables for night and overwater operations to address these conditions with the model.

4. Fatigue

Fatigue is very common for service members to experience in their daily operating schedule. Their environments are unforgiving, and there is little room for mistakes in naval aviation. The combination of the two is a dangerous mix, and it is an unfortunate reality to aviators, especially under circumstances of operational necessity. Salazar (2016) examined different forms of fatigue and their effects over time. He found one commonality among the different forms of fatigue, a negative impact on a person’s ability to perform tasks. The negative impact on performance can be detrimental to the operation of an aircraft. This study aims to create a formula to determine whether the level of fatigue correlates to the likelihood of a mishap, based on how many hours a person has flown in the past one, seven and 30 days.

5. Proficiency

Natural conditions and fatigue, mentioned previously, have direct effects on the likelihood of an aviation mishap. Previous studies found that low levels of proficiency have a profound effect on the likelihood of a mishap for a given flight. These low proficiency levels could be found in the lack of practice due to a shortage of flight hours or other circumstances that prevent a pilot from flying. This study attempts to account for low proficiency levels by including key variables that measure low flight hours on the likelihood of a mishap.

6. Guiding Publications

Numerous publications provide general and specific information on different type of missions and the conduct to carry out those missions. However, publications from two entities are essential to every mission flown by the Navy: the *Naval Air Training and Operating Procedures Standardization manual* (NATOPS) and Chief of Naval Operations Instructions (OPNAVINST).

The NATOPS provides standardized operating procedures for naval aircraft. NATOPS procedures provide the basis by which the best decision can be made by a pilot in handling the dynamic nature of the aircraft under most circumstances. However, NATOPS is not “a substitute for sound judgment” (Naval Air Training and Operating Procedures Standardization [NATOPS], 2009, p. 62). To reduce the likelihood of failure, every decision made by the helicopter aircraft commander (HAC) must be based on not just a single condition but rather the combination of multiple conditions. NATOPS advises, “operational necessity may require modification of the procedures” (NATOPS, 2009, p. 62). It is incumbent upon the HAC to make that decision for the flight.

The OPNAVINST 3710.7U issued by the CNO, provides policy and procedural guidance to all naval aviation entities (Office of the Chief of Naval Operations [OPNAV], 2009). This instruction, used in conjunction with NATOPS, provides the best possible guidance to aircraft commanders in carrying out mission objectives. It should be noted that these instructions serve only as a foundation on which the best decision could be made in the general realm of flight. They are not all encompassing and do not replace

the judgment of the pilot. The pilot's decisions during the flight ultimately determine the success of a mission outside natural causes.

C. OBJECTIVE

These research questions aim to address the relationship between flight hours and mishaps:

1. Does the aggregate number of flight hours in the past day/week/month affect a person's likelihood of having a mishap?
2. Does the number of daily squadron hours in the past day/week/month affect a squadron's likelihood of having a mishap?
3. Does a (sequester) period of reduction in the number of flight hours increase the likelihood of a mishap?

Aggregate standardized flight hours from the past day, week, and month (30 days) are used for our models. Additionally, to determine whether the reduction in the number of flight hours increases the likelihood of maintenance mishaps, we built comparative models of aviation ground related mishaps utilizing the previous flight mishap model's independent variables and compared it to flight related mishaps. Specifically, the aviation ground mishap (AGM) used in our data are from to maintenance related activities. The AGM model used flight hours as an indicator of operating tempo (OPTEMPO) to measure the likelihood of a maintenance mishap. High numbers of flight hours could be an indicator for high levels of OPTEMPO, which affect the likelihood of a mishap.

D. SCOPE, LIMITATIONS, AND ASSUMPTIONS

The aim of this research is to develop an analytical working background to determine the likelihood for naval aviation related mishaps. Within the model, the focus will be on identifying key causality factors contributing to aviation related mishaps. The primary consideration with the research is to create a model that can be replicated for use in further research. For the base model of this research, only flight data for H-60 series rotary aircraft were used.

The research conducted will be a quantitative analysis of the relationship between flight hours and mishaps. The research plan is to conduct an individual and aggregated

squadron-level analysis of flight hours on the number mishaps. The two datasets used for analysis are H-60 series helicopter daily pilot flight hours and mishap incidents from FY00 through FY16. All flight hour data are pulled from active duty rotary winged, H-60 naval aviators.

The Naval Safety Center (mishaps) and Naval Air Systems Command (flight hours) provided the data for this research. Dependent variables are mishaps, categorized by flight, ground, and combined. Independent variables include: individual level daily flight hours, squadron-level daily flight hours, night flights, overwater flights, and sequestration. There are 8,057 pilots in this study, and over 1.2 million observations. The regression model uses Stata statistical analysis software.

It would also be virtually impossible to capture every mission set used for the regression. Certain missions are classified, while other missions do not have accurate records. This research instead captured the unique night and overwater capabilities that are coded in any missions as a requirement. The result is a standardized set of data across the entire group of observations. In return, if a flight was conducted under those conditions, the data provided accurate information to our model to evaluate whether they have statistically significant impact on mishaps.

This research focuses only on the number of past flight hours to estimate the likelihood of a mishap. It does not account for how much training a person previously had or how much time had elapsed since his or her last training evolution. The model made assumptions on the standardized training levels of all pilots.

Flight mishaps and flight related mishaps are directly connected to a flight event through the crew involved. Aviation ground related mishap cannot be accurately measured by the number of flight hours alone. The number of flight hours for AGM serve to address OPTEMPO. High OPTEMPO does contribute to increased stress, ultimately resulting in an increased likelihood of making a mistake.

E. ORGANIZATION OF STUDY

The remainder of thesis is organized as follows. Chapter II reviews the literature on readiness versus proficiency, aviation mishap rate, sequestration, the BCA, and fatigue. Chapter III describes the data and methodology used in this thesis, while Chapter IV provides an analysis of the results from our model. Finally, Chapter V ends with the conclusions and recommendations.

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II. LITERATURE REVIEW

This literature review addresses previous research and literature of the variables for the models in this study. An understanding of sequestration and the decrease in the number of flight hours establishes a link to how proficiency levels may influence the number of mishaps. Hobb's (2013) research on the rate of mishap, based on extended reduced periods of flight hours, gives perspective on the ratio of mishaps to flight hours. The research of Smith and Brobst (2010) addresses complacency and tactical proficiency as factors to safety of flight and relationship to mishaps. For the Center for Naval Analyses (CNA), Brobst, Thompson, & Brown (2006) conducted a comparative analysis on the number of mishaps on units deployed versus those homebased. Their analysis provides an in-depth look at fatigue and increased stressed conditions that influenced the rate of mishaps during periods of increased OPTEMPO. Additionally, the study of Brobst et al. (2006) also looks outside of fatigue at other aircrew causal factors relating to mishaps. Highlighting the effects of fatigue as it relates to high number of flight hours gives a better understand of how those hours influence the likelihood of a mishap. It allows the models in this research to analyze if fatigue from the previous high number of hours flown have any effects on the likelihood of mishaps.

A. READINESS VERSUS PROFICIENCY

Readiness is the ability of a person or squadron to engage in combat at any given time, and proficiency is the ability of a person or squadron to pass training requirements for readiness. The research of Smith and Brobst (2010) into naval aviation tactical proficiency defines readiness as "the number of training and readiness (T&R) points accumulated over a training interval (TI)" (p. 51) to meet the standards of the commander naval air forces (CNAF). These are similar across communities in naval aviation as well as at the individual or squadron levels. These points accumulate based on prescribed sets of training objectives set forth by the CNO and delineated by type, model, and/or series (T/M/S) required operational capacity (ROC)/project operational environment (POE) statements. The number of flights and the aircraft maintenance readiness of a squadron

heavily influence training and readiness (T&R) points. If a squadron is operating at reduced numbers of flight hours or does not have sufficient funding to order parts for aircraft maintenance, it will not fly and will not meet T&R points for a training interval (TI).

Proficiency in naval aviation results from meeting T&R requirements and individual pilot performance abilities. Smith and Brobst (2010, p. 65) further define proficiency, for example, as a set of "tactical flying skills … built through repeated practice concentrated in a short period of time and then … sustained through periodic practice." This is especially true in their analysis of real-world fixed-winged bombing operations. To standardize their tests, they examined the missions, tactics, weapons, targets and conditions for four operations in the Middle East (Smith & Brobst). They analyzed the missed distance for each bombing drop from their baseline against the aircrew's previous training in the past few days to time elapsed from the past deployment (Smith & Brobst). From this data, they isolated variables quantifiable in estimating aircrew-bombing accuracy based on training experience to create a predictive hit percentage model.

Smith and Brobst's (2010) model summary in Figure 1 shows sustained levels of proficiency after conducting Air-to-ground Strike Fighter Advanced Readiness Program (A-G SFARP). During A-G SFARP, aircrews who conducted concentrated training or frequent combat drops saw a rapid increased in accuracy from their baseline (marked by the A-G SFARP arrow pointing to the vertical line in Figure 1). Observations of the average first sea tour aircrews conducting A-G SFARP (100–460 hours [hrs]) show that the percentage of bombs hitting targets increased from 30 to 68 percent, a 127-percentage increase in accuracy. Continued training onward for the second (600–1000 hrs), third (1350–1700 hrs) and fourth (1900–2300 hrs) A-G SFARP tier achieved 100, 72, and a 51 percent increase hit-target from their tier baseline over the period of three career tours. There was a substantial drop in accuracy immediately following every A-G SFARP event. However, continued bombing drops every 60 days maintained the levels of proficiency over time (marked by the horizontal line following every A-G SFARP in Figure 1). This shows that training allows for sustained levels of proficiency and those

levels of proficiency continue to increase if maintained with every consecutive career tour. However, Smith and Brobst noted in their study that aircrew who did not receive sustainment training had “expected hit percentage decrease over time” (2010, p. 19).

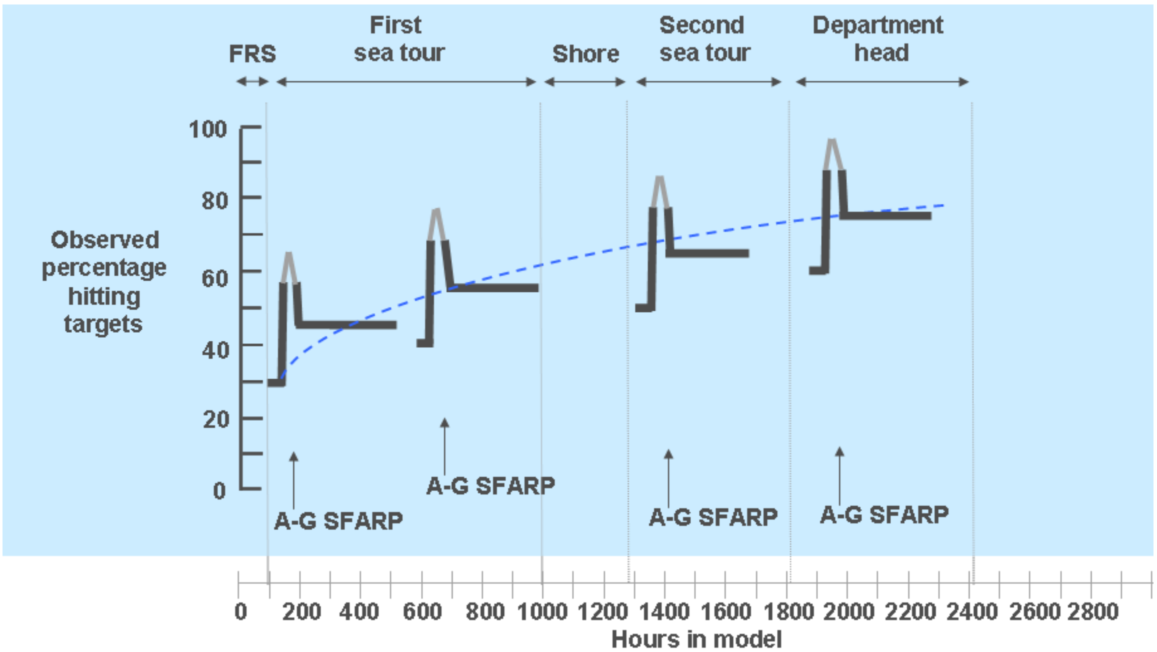


Figure 1. A-G SFARP Hours in Model. Source: Smith and Brobst (2010.)

Other human limitations, such as memory decay and interference theory, also affect proficiency; both are preventable through sustainment training. According to Hoffman et al., achieving and maintaining high proficiency is very difficult in complex and sociotechnical professions due to memory decay (2014). This is particularly true with naval aviators assigned collateral duties and watching standing requirement on top of the flight schedule. Additionally, if the rapid skill decay is left unchecked, the aviator will require costly retraining, putting increased strain on a tight military budget. This perishable skillset must be regularly refreshed to maintain high proficiency levels.

Hoffman et al. also found that “the rate of decay does not depend on the degree of original learning” (2014, p. 40), rather, it is from chemical reactions in human brains that causes those learned things to fade slowly overtime. In addition, Hoffman et al. (2014, p. 40) discovered that no matter how much knowledge a person gains from learning initially

and despite individual differences in learning abilities, they have one thing in common, “the rate of forgetting.” Theoretically, two people can learn to land an aircraft on a moving platform, at different paces, but that skillset takes on the same rate of decay when not sustained.

Figure 2 shows the progressive performance degradation on the average distances missed on targets of fighter pilots on bombing runs, eight weeks after extensive training at NAS Fallon Top Gun School. The figure displays two weeks of training, followed by six weeks of readiness (combat ready). Pilots’ peak levels of proficiency was at the one-and-a-half to two weeks period with a near 50 feet average missed distance (FMD). There is a 50 percent reduction in their accuracy, from 50 FMD to 75 FMD, just a week after training (Hoffman et al.). An exponential reduction in accuracy is noted at the eight-week mark, at roughly 190 FMD—a 153 percent increase from the three-week mark.

This analysis highlights the effect of one required skillset atop many others in naval aviation. All of these are required to meet a combat readiness level. Consistent training on all skillsets are crucial to maintain high levels of proficiency. Cutting corners in the training requirement based on budget constraints will lead to costly retraining and lower levels of proficiency overall. Similar for H-60 pilots, the rate of decay in human memory will ultimately lead to lower levels of proficiency with the reduction in the number of flight hours over time. The unifying variables for Hoffman’s study on fixed winged and rotary winged aviation are the complex and socio-technical aspects of these professions, which required sustained training to maintain high levels of proficiency. The reduction in the total number of flight hours affects readiness levels when T&R points are not met. These points result from not meeting all required training objectives for a mission, based on the level of proficiency of a pilot to meet assessment criteria. Additional points are lost when an aircraft is down, losing valuable training hours for the squadron.

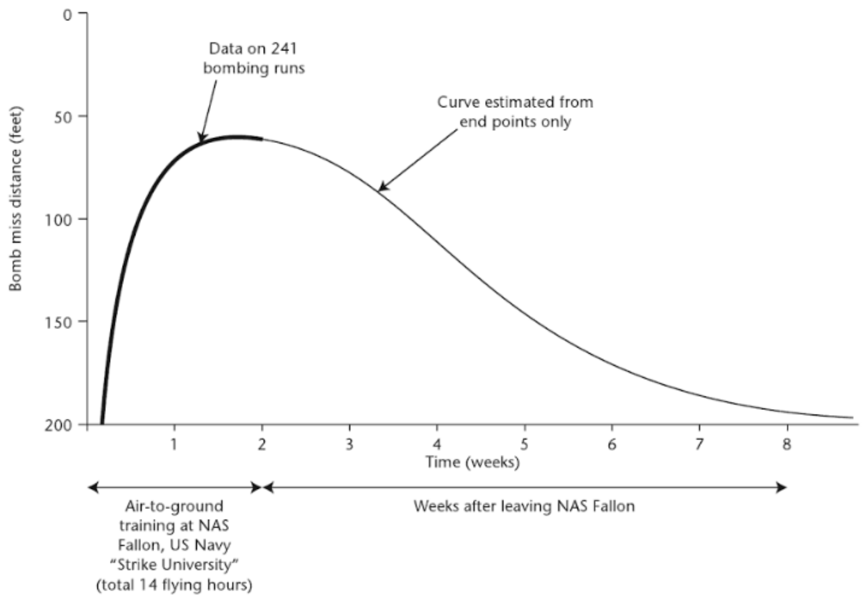


Figure 2. A Performance Decay (or "Forgetting") Curve.
Source: Hoffman et al. (2014).

A successful mission depends on the pilot's proficiency in carrying out the tasks. Proficiency varies between individuals; it cannot be set based on a standard set of regulated flight hours. It would be inaccurate to measure a person's proficiency level based solely on flight hours. An individual pilot's ability (cognitive measurement) and competency to successfully complete a mission, is different in every individual. Repetition is vital to proficiency, and fewer flight hours compromise high levels of proficiency.

The *Naval Aviation Vision for 2016–2025* leans heavily on the readiness and training requirements to optimize aircrew proficiency (Department of the Navy [DON] & U.S. Marine Corps [USMC], 2016). Squadron readiness levels depend on the type wing commander's squadron training requirements. For instance, if a squadron is required to have eight HACs and that squadron is currently at six, it is below combat readiness levels. CNAF (or the airboss) is keen on the idea that "readiness remains the essential key to our warfighting proficiency" (DON & USMC, 2016, p. 4). However, it is harder to maintain proficiency when there is reduce funding covering fewer flight hours and the same requirement to balance readiness levels. The reduced funding has a direct negative

impact on maintenance’s ability to acquire parts in order to sustain ready-based aircraft (RBA) levels to the warfighter as well as to meeting T&R for CNAF. An article from the *San Diego Union-Tribune* highlights the effect of sequestration on Marine aviator safety, showing how the lack of funding results in low aircraft readiness levels (Schafer, 2017). Ultimately, this attributes to the deadly crash of a CH-53E (Schafer, 2017). In a testimony to Congress, Schafer quoted Marine Corps Commandant General Robert Neller saying, “our aviation units are currently unable to meet our training and mission requirements” (Schafer, 2017). The article is a testament to one of the many effects of sequestration and its effect on naval aviation.

Furthermore, readiness levels are established based on the requirement to sustain combat operations from the ROC/POE documents and manning requirements in the squadron manpower document (SQMD). When budget constraints create reductions in the number of flight hours, those flight-training hours must be achieved elsewhere. In some cases, a simulator would be considered a suitable substitute; however, simulators do not replicate the true dynamic and ever changing nature of an actual flight environment. Glenn Jr. and Otten’s research on readiness demonstrates that the reduction in requirements to achieve certain level of readiness had limited savings on the managing of budget constraints, but “at a certain point, the reductions will have a noticeable effect on actual performance” (Glenn Jr. & Otten, 2005, p. 24). Additionally, Glenn Jr. and Otten (2005) concluded that reduction in training had a small effect on overall budget but large effect on individual performance. In their research analysis of F-18 Super Hornet, Smith and Brobst came to the same conclusion, noting, “Cutting funding by half, from 16 FH [flight hours] per month to 8 FH per month, leads to, at most, cost savings of 50 percent, but increases the likelihood of a mishap by 75 percent” (2010, p. 15).

The measurement of reduced proficiency can truly be assessed two ways, through the levels of mishaps and in combat against adversaries. Neither is desirable. As Glenn Jr. writes, “discovering poor performance due to readiness-level reductions during combat is too late” and furthermore, puts lives at unnecessary risk (Glenn Jr. & Otten, 2005, p. 25). Through his research into CNAF flight hours program on budgeting requirement, Glenn Jr. discovered that “any net reduction in the hour requirement will have a direct and

significant effect on the funding needs of the program" (Glenn Jr. & Otten, 2005, p. 24). This leads to a chain reaction throughout aviation from cutting funding to the total number of flight hours to THD. This research aims to measure whether the reduction in the number of flight hours results in an increase in the number of mishaps based on a model that measures low number of flight hours as an indicator for low levels proficiency.

B. AVIATION MISHAP RATE

A person must fly often to remain current and maintain high levels of proficiency; however, there are necessary conditions to fly. Some examples include funding of flight hours, proper scheduling, and aircraft maintenance. Not meeting these conditions disrupts squadron operations, leading to lost flights and fewer flight hours. In turn, these fewer flight hours lead to reduced levels of proficiency and potentially an increase in the likelihood of a mishap. If policymakers are not aware of these effects, they could make risky decisions concerning the funding of flight hours. The data analysis of flight hours and aviation mishaps may reveal insight to a policy that reduces the number of flight hours based on budgetary cuts and its effect on the likelihood of a mishap.

Hobb's (2010) research into F-18 mishaps during extended periods of reduced flight hours provides some insight into the relationship of flight hours and the rate of mishaps. His research analyzed numerous data and summarized it in a simple table for periods of reduced flight hours. In his research, Hobbs identified periods of reduced flight hours and used the sum of flight hours for that period as the denominator under the number of mishaps and multiplied by 100,000 to determine the mishap rate. The data for this research spans from FY 1990 to 2013. Hobbs determined periods not represented as "a period of reduced flight hours" to be categorized as normal periods (Hobbs, 2013, p. 4). Hobbs determined period of reduced flight hours through a regression analysis that compared individual periods to the aggregate date set. Those periods considered periods of reduced flight hours had a p-value less than .05. Column 2 in Table 1 represents the total number of mishaps, and column 3 represents the total number of flight hours. The

result, in Table 1, panel A, indicates an increased in the rate of mishap during the period of extended reduced flight hours.

Table 1. Class A/B/C Flight/Ground Mishap Rate per 100,000 Flight Hour Comparison. Source: Hobbs (2013).

Period	Flight Mishap Class A/B/C	Flight Hours	Rate
Panel A: Flight Mishap			
Reduced Flight Hour	37	218,669	16.92
Normal Operations	228	2,062,184	11.06
Panel B: Ground Mishap			
Reduced Flight Hour	12	218,669	5.49
Normal Operations	195	2,062,184	9.46

To determine if the two rates in panel A of Table 1 are statistically significant and different, "a test for proportion with the two mishap rates was conducted with a resulting p-value of .041" (Hobbs, 2013, p. 21). This means the data support the assumption in which a reduction in the number of flight hours increases the rate of mishap. If F-18 squadrons are forced to operate at continual tactical hard deck or reduced flight hours, the result could be an increase in the number of mishaps.

On the other hand, the effects may be different for ground mishaps. According to Hobbs (2013, p. 15), the data "provide an indication of squadron OPTEMPO," as shown in panel B of Table 1, and highlight the effect of the period of reduced flight hours on ground mishaps. Ground mishaps cannot be measured based only on flight hours since it does not involve a flight or the intent to fly. To measure the effect of ground mishaps, flight hours are used as an indicator to measure the OPTEMPO of a squadron. More flights will lead to more hours of maintenance, which could result in increased levels of stress and potentially lead to an increase in the likelihood of a ground mishap. A test for proportion resulted in a p-value of .041, which indicates that the period of reduced flight hours is statistically significant from a period of normal operations. From this, we can assume that OPTEMPO affects maintenance personnel when lower levels of OPTEMPO

reduces the levels of fatigue to ground personnel. The lower levels of OPTEMPO translate to a reduction in the rate of ground mishaps, opposite to flight mishaps.

Figure 3 highlights the trend for all Navy class A mishap rates from 2002–2016. Figure 3 data does not represent all types of mishaps, rather it is limited to the most severe, class A—death or total loss of aircraft. This figure shows a spike in the number of class A mishaps in FY 2013, which is also coincidently the same year in which sequestration took effect on the DOD budget. Although the mishap rate does subsequently trend downward the following years, it could indicate a change in the training and risk management processes developed by the type wing commanders to deal with the effect of sequestration.

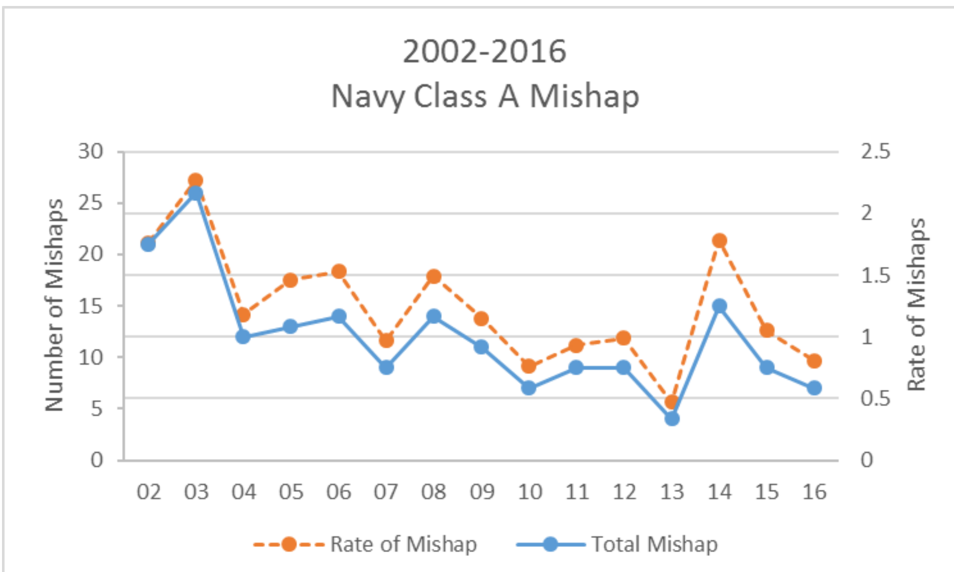


Figure 3. FY02–16 Navy Class A Flight Mishap Rates. Source: Navy Safety Center (2017).

While Hobb's research (2010) focused on the rate of mishap, this research examines the aggregate number flight hours at the individual and squadron level to determine the likelihood of mishaps. The models provide a more accurate measure of the nature behind the mishap and those periods of sequester. Furthermore, this research aims

to find evidence as to whether sequestration had an impact on naval aviation through a third-party lens, rotary winged aviation.

C. SEQUESTRATION AND THE BUDGET CONTROL ACT

Sequestration is the by-product and control mechanism of the Budget Control Act (BCA) of 2011. For defense spending, the BCA created a budget cap for a 10-year period ending in FY 2021. According to a Congressional Budget Office (CBO) report in 2011 (2011), within this period, the goal was to reduce defense spending by $492 billion dollars or $55 billion annually. However, Belasco (2015, p. 2) noted in his report that if at any time "Congress enacts a spending level that exceeds BCA caps for the defense base budget, the president is required to sequester or levy across-the-board cuts to each type of defense spending to meet the BCA caps," which have immediate impact to funding for military operations.

The BCA has some exceptions. A major one is "war-designated funding" (Belasco, 2015) or overseas contingency operations (OCO), which are broadly defined and not subject to spending limits. However, since the OCO was not well defined for what constitutes contingency funds, government analysts have interpreted it to be an "undermining mechanism meant to fund incremental costs of overseas conflicts and fails to provide a stable, multi-year budget on which defense planning is based" (Belasco, 2015, p. 2). That is, if a squadron exceeded the monthly allotted flight hours granted by the wing commander, the commanding officer (CO) for that squadron can request additional flight hours. The funding for those flight hours would be approved as OCO funding.

Reducing the defense spending does not account for inflation or the cost of readiness. However, it may develop a stagnant force that is now ultimately unable to meet the expected demand of future threat readiness. Belasco also reported, "defense spending would be equivalent in real terms (the same purchasing power) to the level between FY2007 and FY2008" (2015, p. 2). In other words, the demand for readiness levels exceed the funding to meet the requirements. That need in particular, is the ability to provide a defense for expected future threats of the nation. What is more troubling is the

way the FY 2013 sequester was handled in the short term. The DOD offset the budget by "cancelling or shortening unit training for those units not preparing to deploy" (Belasco, 2015, p. 29). This meant that if a squadron was not on the schedule to be deployed, or if it has just come back from a deployment and is in a stand-down phase of operations, it would have to operate at THD. This results in lost training opportunities and reduced aviator proficiency. Naval aviation strives to be perpetually ready and to train as it fights. Unfortunately, the BCA mandated policy that resulted in a reduction in the number of flight hours and operating at THD make those goals obsolete.

D. FATIGUE

Experiencing fatigue is a normal part of military culture. The researcher has experienced the full effect of chronic and operational fatigue throughout his military career, as both an aircraft mechanic and a pilot. People deal with fatigue by taking a nap. For those who stand the watch to defend their country, that is simply not an option; it is an inconvenient way of life. The amount of responsibility and the complexity of a job can exponentially increase the hazard associated with fatigue. OPNAVINST 3710.7U states, "Operational commitments may necessitate continuous and/or sustained operations in which sleep and circadian rhythms are disrupted, leading to potentially hazardous fatigue" (OPNAV, 2009, p. 8-4).

The Federal Aviation Administration (FAA) has conducted numerous independent studies on the effect of fatigue on pilots in aviation, including standardized laboratory testing and in-cockpit observations of pilots. From the studies, the FAA concluded that fatigue "significantly impaired a person's ability to carry out tasks that require manual dexterity, concentration, and higher-order intellectual processing" (Salazar, 2016, p. 2). Furthermore, in comparison to civilian pilots, naval aviators are more prone to circadian disruptions due to early morning and night flights that required unusual sleeping and waking patterns, along with watch standing requirements.

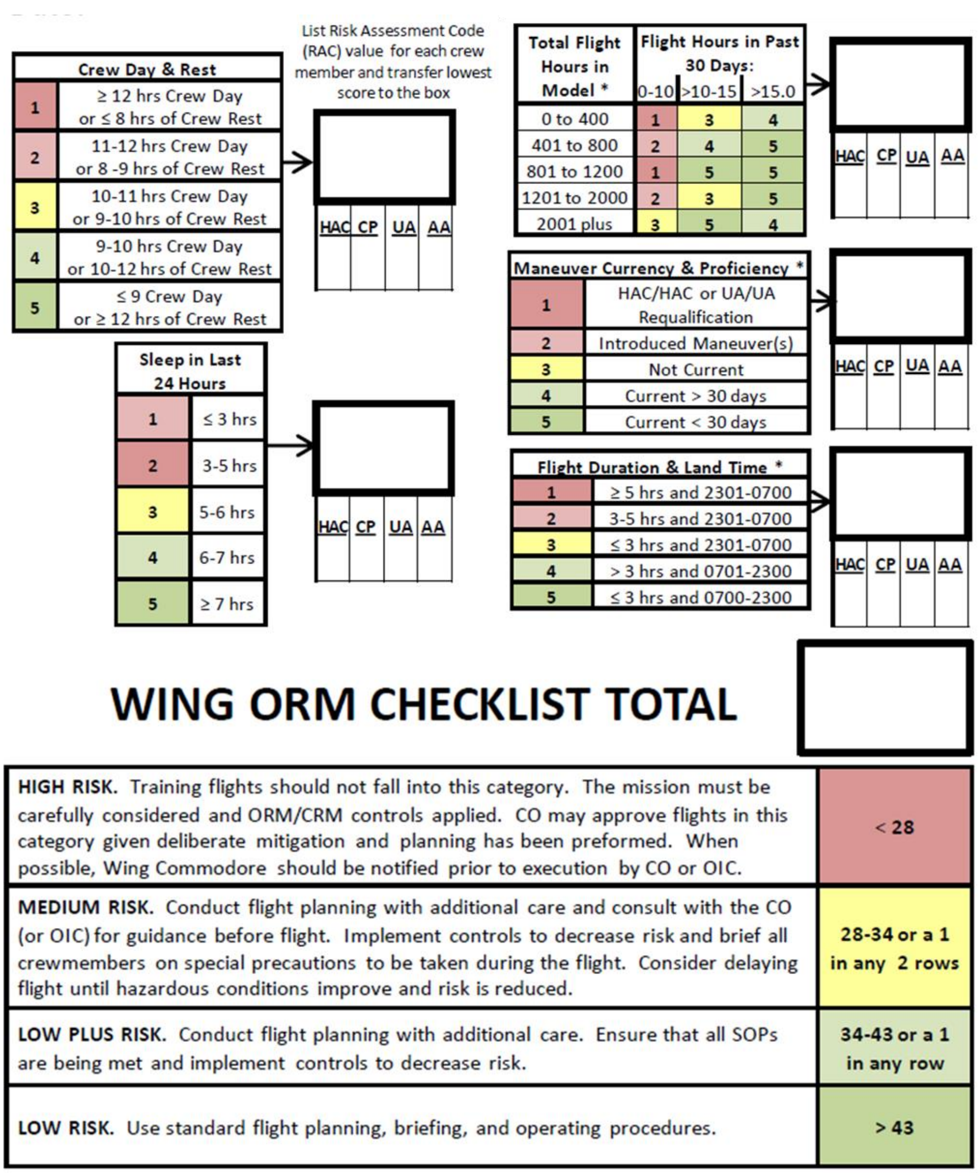
During periods of deployment or sea transit, naval aviators have to quickly adapt to time zone changes. Naval Aviation Schools Command (2005) reports the Naval Aerospace Medicine Institute (NAMI) conducted independent studies and also looked at

numerous scientific studies on the effect of sleep, including one done by Australian researchers comparing the effect of fatigue to alcohol intoxication (Naval Aviation Schools Command, 2005). The NAMI studies discovered performance levels from being awake for 22 hours were comparable to a person with a blood-alcohol level of 0.08% (Naval Aviation Schools Command, 2005). According to OPNAVINST 3710.7U, guidance from NAMI suggest, "Changing local sleep/awake periods or rapidly crossing more than three time zones disrupts circadian rhythms and can cause a marked decrease in performance" (OPNAV, 2009, p. 196). OPNAVINST 3710.7U (2009) states that it takes a full day to acclimate to every three-time zone crossing, in addition to setting a new daily routine. Unfortunately, the nature of military aviation does not afford personnel those opportunities.

Chronic fatigue can create excessive stress levels in a person, leading to "mood and behavior changes and to deteriorating performance" (Chief of Naval Operations [CNO], 2004, p. 200). Chronic fatigue comes from having an overly busy and stressful schedule, something all too common in day-to-day operations during deployments. No quick and easy solutions can cure chronic fatigue; it takes time and rest. In order to combat chronic fatigue and to reduce the likelihood of having a mishap, OPNAVINST 3710.7U (2009) outlines a mandatory limitation on aviators' crew rest and sleep. This OPNAV instruction also provides guidelines for the maximum daily and weekly flight time a person should have to prevent excessive stress and chronic fatigue. It stipulates no more than three flights or 6.5 total flight hours per day and no more than 30 hours a week (OPNAV, 2009).

Squadrons use a commander, Helicopter Sea Combat Wing (COMHSCWINGPAC) operational risk management (ORM) sheet (shown in Figure 4) to help determine the likelihood of having a mishap prior to a flight. It accounts for fatigue, currency, proficiency, and time of flight using a risk assessment code (RAC). Fatigue is measured in the boxes for crew day and rest, sleep, and flight duration. Currency and proficiency are measured both boxes for the total flight hours in model and maneuver currency and proficiency. If the sum of the RAC falls within a category considered "high risk," it would be up to the CO to approve the flight. Based on the ORM

sheet, the research assumes that all individuals in the database have a constant safe level of human factors for each flight, which means that there is no one person (an outlier) who is overly stressed or at a higher risk than anyone else to skew the effect of mishap.



List Risk Assessment Code (RAC) value for each crew member and transfer lowest score to the box

Crew Day & Rest	
1	≥ 12 hrs Crew Day or ≤ 8 hrs of Crew Rest
2	11-12 hrs Crew Day or 8 -9 hrs of Crew Rest
3	10-11 hrs Crew Day or 9-10 hrs of Crew Rest
4	9-10 hrs Crew Day or 10-12 hrs of Crew Rest
5	≤ 9 Crew Day or ≥ 12 hrs of Crew Rest

HAC	CP	UA	AA

Sleep in Last 24 Hours	
1	≤ 3 hrs
2	3-5 hrs
3	5-6 hrs
4	6-7 hrs
5	≥ 7 hrs

HAC	CP	UA	AA

Total Flight Hours in Model *	Flight Hours in Past 30 Days: 0-10	>10-15	>15.0
0 to 400	1	3	4
401 to 800	2	4	5
801 to 1200	1	5	5
1201 to 2000	2	3	5
2001 plus	3	5	4

HAC	CP	UA	AA

Maneuver Currency & Proficiency *	
1	HAC/HAC or UA/UA Requalification
2	Introduced Maneuver(s)
3	Not Current
4	Current > 30 days
5	Current < 30 days

HAC	CP	UA	AA

Flight Duration & Land Time *	
1	≥ 5 hrs and 2301-0700
2	3-5 hrs and 2301-0700
3	≤ 3 hrs and 2301-0700
4	> 3 hrs and 0701-2300
5	≤ 3 hrs and 0700-2300

HAC	CP	UA	AA

WING ORM CHECKLIST TOTAL

HIGH RISK. Training flights should not fall into this category. The mission must be carefully considered and ORM/CRM controls applied. CO may approve flights in this category given deliberate mitigation and planning has been preformed. When possible, Wing Commodore should be notified prior to execution by CO or OIC.	< 28
MEDIUM RISK. Conduct flight planning with additional care and consult with the CO (or OIC) for guidance before flight. Implement controls to decrease risk and brief all crewmembers on special precautions to be taken during the flight. Consider delaying flight until hazardous conditions improve and risk is reduced.	**28-34 or a 1 in any 2 rows**
LOW PLUS RISK. Conduct flight planning with additional care. Ensure that all SOPs are being met and implement controls to decrease risk.	**34-43 or a 1 in any row**
LOW RISK. Use standard flight planning, briefing, and operating procedures.	**> 43**

Figure 4. Commander, Helicopter Sea Combat Wing ORM Sheet 3710.7E 5E. Source: COMHSCWINGPAC (2017).

The analysis of flight hours in this research takes fatigue into account based on the number of aggregate lagged hours a person or squadron has flown within the previous

day, week, and month. Furthermore, the lagged days used coincide with the maximum recommended flight time prescribed by OPNAVINST 3710.7U as a measure of fatigue (OPNAV, 2009).

III. DATA AND METHODOLOGY

A. INTRODUCTION

This chapter provides an in-depth description of the data and methodology used in this thesis. The following sections describe the data source, key variables, and conceptual framework for conducting the research. Additionally, this chapter provides a description of the theoretical approach for the models. I elected to use data for the H-60 helicopter community because of my personal experience with both ground maintenance and piloting of the rotary aircraft.

B. DATA SOURCES

The two datasets used for the research analysis are the daily individual pilot hours and mishap incidents for the H-60 series helicopter from FY00 through FY16. The Naval Safety Center (NAVSAFECEN) and Naval Air Systems Command (NAVAIR) provided the data. The two sets of data can only be linked by date, time, and squadron.

NAVSAFECEN maintains a collection of historical mishap data through a web-enabled safety system (WESS) employed by all naval squadrons. According to NAVSAFECEN, "WESS provides an on-line, interactive, electronic means of managing information and consolidating all types of incidents into one consolidated database" (2013). All naval aviation mishap incidents must be reported by federal law in accordance with Occupational Safety and Health Administration in 29 CFR §§ 1904 and 1906. All naval aviation mishaps must be reported to maintain accurate record keeping and help reduce future occurrences of similar events. Additionally, Department of Defense Instruction (DODI) 6055.07 (2011), OPNAVINST 5100.23G (OPNAV, 2005b), and OPNAVINST 5102.1D (OPNAV, 2005a) provide requirements and reporting guidelines. Data requested from NAVSAFECEN came through a Freedom of Information Act request with all personal identifiable information removed.

NAVAIR uses Decision Knowledge Programming for Logistics Analysis and Technical Evaluation (DECKPLATE) software for the collection flight data. According to NAVAIR, "DECKPLATE is a reporting system, based on the Cognos analysis, query, and reporting tool" for which historical flight data can be collected and distributed for analytics (n.d.). Additionally, DECKPLATE—Aircraft Inventory and Readiness Reporting System is the Navy's official aircraft inventory program for all aircraft and flight hours reporting. Squadrons' maintenance control personnel log all individual flights in the Naval Aviation Logistics Command Management Information System (NALCOMIS), which later reports data to NAVAIR DECKPLATE for archiving. All historical aircraft flight hours' data collected through DECKPLATE contain detailed information of all flights flown in naval aviation—specifically, date, time, hours, mission, pilot identification, etc. The data received from NAVAIR had all social security numbers (SSNs) and personal identifiable information (PII) replaced by randomly generated identifiers for each individual person.

C. PANEL DATA

The data received from NAVAIR included data on individual pilots and their respective squadron flight hour, along with respective flight essential log entries. NAVSAFECEN categorized the data by squadron date and time of mishap along with other essential mishap information. This information was kept unclassified and unlimited in distributions to allow for wider readership. PII and the specific number of flight hours was kept secured for operational security reasons relating to the OPTEMPO of the squadrons. In lien with that decision, squadrons, dates, and times of individual flight events were chosen rather than SSN of individual to be key variables used to merge two datasets.

To create a longitudinal data set suitable for use in Stata, the two datasets in Excel format were combined into one using the following key variables:

- Squadron—official squadron name, home-base, and respective detachments.
- All squadron names from both datasets were reformatted to standardize both datasets and to avoid errors in Stata software analysis.

- Dates and times—date of mishap and time of mishap were used to match flight event date and time for a particular squadron.
- Flight related mishap data from NAVSAFECEN was merged in Excel, one event at a time, with NAVAIR data to reduce the likelihood of error. All ground data from both datasets were merged using Stata software programing.
- Any mishap events from NAVSAFECEN that could not correlate to an individual flight data record from NAVAIR was not merged into the individual level analysis model. No ground mishap data was used in calculating the individual level analysis. Both ground and flight mishap data were used to calculate the squadron level analysis.

D. ORIGINAL DATA VARIABLES

The following data variables are described according to their Excel row heading as gathered from NAVSAFECEN and NAVAIR. Some of the data variables come directly from NAVSAFECEN and other come from NAVAIR. All variables are in the raw format entries in NAVSAFECEN and NAVAIR system archive. Furthermore, unique variables generated using Stata are not discussed in this section.

1. Departure Date

Departure date describes the exact date a mishap event occurred or the departure date of the flight event.

2. Departure Time

The time the squadron's aviation mishap board determined the incident took place or the departure time of the flight event.

3. Mishap Category (NAVSAFECEN)

Mishaps are categorized by a flight, flight related, or ground mishap. Specifically, there must be damage to the aircraft to be categorized at a flight mishap. A flight related mishap is cause anything other than damage to the aircraft. For an incident to be categorized as a flight mishap, there must be the intention to fly. A ground mishap occurs when an incident takes place without intent for flight. Table 2 gives a detailed definition for each type in accordance with DODI 6055.07 (DOD, 2011).

Table 2. Aviation Mishap Category and Subcategories. Source: DOD (2011).

AVIATION MISHAPS INVOLVE AIRCRAFT OR FLYING OPERATIONS	
Subcategory	Subcategory Characteristics
Flight Mishap (FM)	A mishap where there is intent for flight and damage to DOD aircraft. Explosives, chemical agent, or missile events that cause damage to an aircraft with intent for flight are categorized as flight mishaps to avoid dual reporting. (Mishaps involving factory-new production aircraft until successful completion of the post-production flight are reported as contractor mishaps.)
Flight Related Mishap (FRM)	A mishap where there is intent for flight and no reportable damage to the aircraft itself, but the mishap involves fatality, reportable injury, or reportable property damage. A missile that is launched from an aircraft, departs without damaging the aircraft, and is subsequently involved in a mishap is reportable as a guided missile mishap.
Aviation Ground Mishap (AGM)	A mishap where there is no intent for flight that results in damage to an aircraft or death or injury involving an aircraft. This applies to aircraft both on land and on board ship. Damage to an aircraft when it is being handled as a commodity or cargo is not reportable as an aircraft mishap.

4. Mishap Class (NAVSAFECEN)

The data was categorized into four types of mishap class based on the severity of damage that occurred as a result. A class of mishap is defined by the most severe of total property damage, fatality/injury, or outcome. For instance, if there is permanent partial disability to a person (Class B) and an aircraft is also destroyed (Class A), that incident would be classified as a Class A mishap. If an aircraft is destroyed (Class A), and there is a fatality (Class A), both serve as the cause of categorizing the mishap as class A. Table 3 gives a detailed definition for each type in accordance with DODI 6055.07.

Table 3. Mishap Definitions and Reporting Criteria. Source: DOD (2011).

Mishap Class	Total Property Damage	Fatality/Injury
A	$2,000,000 or more and/or aircraft destroyed	Fatality or permanent total disability
B	$500,000 or more but less than $2,000,00	Permanent partial disability or three or more persons hospitalized as inpatients
C	$50,000 or more but less than $500,000	Nonfatal injury resulting in loss of time from work beyond day/shift when injury occurred
D	$20,000 or more but less than $50,000	Recordable injury or illness not otherwise classified as a Class A, B, or C

5. Aviation Squadron Name / Custodian

The official name of a helicopter squadron involved in a mishap falls under the aviation squadron name / custodian. In some instances, the respective squadron wing send pilots to fly with a squadron and is involved in a mishap. When this occurs, the wings' name is logged. In this case, the name is changed back to the squadron involved in the mishap.

6. FAA Identifier / Bureau Number

FAA identifier / bureau number is the naval aircraft unique serial identification number that is part of NAVAIR—Aircraft Inventory and Readiness Reporting System.

7. Aircraft Type Model

The specific type model series of the aircraft is found under aircraft type model.

8. Unique Individual Identification (NAVAIR)

The category unique individual identification has the unique randomly generated identifier for each individual pilot to replace social security numbers.

9. Total Number of Flight Hours

The total number of flight hours is, as the category suggests, total number of flight hours a person or squadron has flown in a given day.

10. Total Number of Nighttime Flight Hours

The total number of night hours, as the category suggests, is the total number of night hours flown by a person or squadron in a given day. OPNAVINST 3710.7U defines nighttime as "the portion of pilot time during darkness (i.e., between the official time of sunset and sunrise (on the surface below the aircraft in flight), regardless of whether visual or instrument conditions exist" (OPNAV, 2009, p. N6).

11. Mission Code

The mission code is the total mission requirement (TMR) codes. Codes entered into mission 1 are considered the primary mission during a flight. Mission 2 refers to a secondary mission derived from the mission requirement or squadron-training requirement to meet readiness.

E. OUTCOME VARIABLES

Mishap, flight mishap, and ground mishap are outcome variables measured in the research. These variables are dichotomous (dummy variables [DVs]). Mishaps take on the value of 1 if a flight mishap or flight related mishap occurred; otherwise, they have a value of 0 for individual level analysis. At the squadron level analysis, mishaps take on the value of 1 for any mishap that occurred. If no mishap occurred, they take on the value 0. Ground mishaps take on the value of 1 if an aviation ground-related mishap occurred. Otherwise, they are given the value 0. Flight mishaps take on the value of 1 if a flight mishap or flight related mishap occurred; otherwise, they are designated as 0.

F. KEY EXPLANATORY VARIABLES

Aggregate standardized flight hours flown in the past day, week, and month makes up the key explanatory variables. Using standardized values of past flight hours allowed the research to examine how past flights affected the likelihood of a mishap of a

given day in the present. The individual level standardized values were calculated using the sum flight hours in the past day, week, and month minus their mean and divided by their standard deviation across all observations. At the squadron level, standardized values were calculated by individual squadron using aggregate flight hours in the past day, week, and month minus their mean and divided by their standard deviation. The squadron standardization estimates were used to correct for large changes in the standard deviation between squadrons. More specifically, 40 hours above the mean could be a lot more for some squadrons but not so for others. The size of the squadron determines the total number of flight hours. This reflects the different amount of deviation from the mean for a squadron that is small to those that are larger. Standardization by squadron estimates helps to control for these large shifts in standard deviation.

Sequestration is a dichotomous variable used to get better estimates for flight hours. That variable represents the period of sequestration from March 1, 2013, through September 31, 2016. It allows each model to examine if the period of sequestration affected the likelihood of mishaps. The variable does not explain all causes; it only provides an indicator for changes to the likelihood of mishaps during periods of sequestration. Additionally, the estimates for sequestration could have effects beyond what the flight hour data indicates.

G. CONTROL VARIABLES

Night flight is a control variable that takes on the value of 1 if any portion of a flight was flown at night at the individual level or flights at the squadron level. This variable does not include nautical or civil twilight flights, which are outside the scope of this research. Several factors are associated with increased levels of risk in nighttime flying. For example, situational awareness of the terrain environment decreases due to the loss of natural lighting and the structure of the human eye, which causes illusions and blind spots. in addition, night vision devices reduce depth perception of the environment. Moreover, from adjusting to a day sleeping cycle, a pilot’s circadian rhythm changes during periods of night flight. All these factors contribute to the increased risk during

night flights. For those reasons, it is important to examine the effects of these factors on mishaps.

An overwater flight is represented by a dichotomous variable that takes on the value of 1 if the TMR code for a mission is dependent on operations overwater. OPNAVINST 3710.7U established that "the TMR code is developed from a three-character code matrix with the first character representing the flight purpose, the second character representing the general purpose, and the third character representing the specific purpose" (OPNAV, 2009, p. D-1). This overwater flight variable is used to explore the relationship of flights overwater on the likelihood of a mishap.

H. VARIANTS OF MODEL

This section provides a description of the variations of models created for the research.

1. Fixed Effect Logit

This study utilized a logit model to address nonconforming predicted probability in the linear probability model. The dependent variable (mishap) is dichotomous. Using a logit model allows an estimate of the dependent variable based on an odds ratio or the probability that an event happened. Fixed-effects (FE) are used in logit models to control for several forms of omitted variable bias. Different squadrons or detachments of a squadron vary in size of personnel and helicopter; this variance could influence the probability of a mishap. Different individuals have different variations within their flight schedule and lives. In addition, geographical location could influence the flight scheduling because of good or bad weather. This unobserved heterogeneity among the key explanatory variables could be pragmatic to the estimates, creating the potential for omitted variable bias. The fixed effect model controls for omitted variable bias and allows for intra-individual/squadron estimates.

2. Individual versus Squadron Estimates

The models were created using panel data based on the temporal order of individual observations. For an individual or squadron at the aggregate level, i represents

an observation. For a period of time, t represents the chronological sequence of i. Two model variants were developed. The first contains all the required variables for an individual level analysis. The other includes individual level data, collapsed at the squadron level. Furthermore, the squadron level collapsed data allowed the researcher to make models that had aggregate daily flight hours for each individual squadron for a given date, allowing for a squadron level analysis.

Panel data, also known as longitudinal data, was used to build the models for our analysis. This method is appropriate for our model based on the number of daily flight hour data on pilots over a period. This set of data provided the research with multiple observations for each individual pilot over a length of time. The same data is used with the squadron level analysis.

An examination of the models at the individual level provides average mishap estimates based on the direct number of hours a person had flown. It allowed the research to identify if flying too many hours (high fatigue) or too few (low proficiency) can influence a person's likelihood of being involved in a mishap. Furthermore, the individual analysis provided insight into whether policy decisions on the funding of the total number of flight hours could affect individual performance. The disadvantage of individual level analysis with using a flight hour's model data is that it cannot predict the likelihood of a ground mishap. Additionally, the individual level analysis estimates do not provide insight into average squadron level performance.

A squadron level analysis provides overall estimates of individuals within each squadron and their cumulative influence on the likelihood of having a mishap. Using aggregate squadron flight hours offer insight to OPTEMPO. The level of OPTEMPO allowed the research to build a model that measured aviation ground mishaps affecting maintenance personnel. The OPTEMPO from the total number of flight hours parallel maintenance-related activity levels. If a squadron flies all of its aircraft, maintenance personnel are stretched too thin to support launch and recovery operations during the flight schedule. Those not on the flight schedule are putting in extra work to fulfill aircraft maintenance requirements. The levels of fatigue of all personnel in the squadron are heavily influenced by the number of hours flown. The disadvantage of having a

squadron estimation is the results are cumulative averages of all individual pilots within the squadron. The effects of an individual on the likelihood of a mishap cannot be measured using a squadron analysis.

3. Different Types of Mishaps

To examine effects on ground and flight mishaps for the given time period, we created three categories of models: Individual flight mishap (FM), Squadron FM, and Squadron ground mishap (GM). Within each set of models were variations based on the type of estimate we wanted to examine. All mishap variables are dichotomous.

The FM models provide unique insight to flight related mishap at the individual and squadron level. FM can only be categorized if the mishap occurred while the aircraft is in flight or with the intent to fly. A qualified aviator is the only person authorized to put an aircraft in that position. This policy uniquely ties each FM directly to an individual pilot at the squadron. No maintenance personnel can be accountable for a FM.

GM are only associated with maintenance personnel since they are not flight related and do not involve individual pilots in our data set. The estimate for GM provides unique insight on the effect of squadron OPTEMPO to maintenance personnel.

4. Lagged Sum Hours

Aggregate standardized lagged hours for the past day, week, and month were used to correct for omitted variable bias, and provide estimates for the effects of fatigue and proficiency. Creating aggregate lagged hours allowed the research to examine whether the numbers of total flight hours flown in the past, from too much flying (fatigue) or too few hours of flying (low proficiency) affect the likelihood of a mishap. These aggregate hours do not encompass all factors of fatigue or proficiency but provide indicators for their estimates on the likelihood of a mishap.

5. Two Approaches

Two different approaches were used as indicators to test for effects of fatigue and proficiency: the first is to measure high and low hours, and the second is to measure

flight hours above and below the mean. Both provided a different variation on the likelihood of a mishap. These are

a. Dummy Variables for High Hours and Low Hours

- High hours are used to measure the effect of fatigue based on the 95th percentile standardized aggregate flight hours. The 95th percentile provides an indicator for fatigue. The variable aims to estimate the average effect of those groups who fly considerably more than the mean hours on the likelihood of a mishap.

- Low hours are used measure the effect of low levels of proficiency at the bottom 10th percentile of standardized aggregate flight hours. The bottom 10th percentile provide an indicator for low levels of proficiency. The assumption is that not flying enough reduces the level of proficiency for an individual or squadron. The variable aims to estimate the average effect of those groups who fly considerably less than the mean hours on the likelihood of a mishap.

b. Spline Piecewise Linear Dummy Variables

- This model was created to estimate separate effects of the number of flight hours below and above the mean for a squadron or for individual pilots. The low variable approximates the effects of flying below the mean flight hours on the likelihood of a mishap. The mean for our model was established to create the change point. The high variable approximates the effects of flying above the mean flight hours on the likelihood of a mishap. The variables for the estimates are as follows:

- H_x ($H_x<0$), where H_x represents the standardized aggregate flight hours, and x represents the specific period for assessment of the past day, week, and month. Low ($H_x < 0$) is the binary variable to represent any standardized flight hours less than 0.

- High ($H_x > 0$) is our binary independent variable to adjust the starting point for the spline-model line above the mean. This variable represents any standardized hours that are greater than 0.

- H_x ($H_x>0$), where H_x represent the standardized aggregate flight hours, and x represents the specific period for assessment. ($H_x > 0$) is the binary variable to represent any standardized flight hours that are greater than 0.

Low ($H_x<0$) and High ($H_x>0$) are dichotomous variables used to interacted with H_x, standardized flight hours. Their interaction allows the model use high and low flight

hours to create indicators for fatigue and proficiency and estimate the likelihood for mishaps.

6. Sampling of Models with Interactions

A squadron level model was created using lagged aggregate seven-day standardized flight hours. The models included the following interactions:

- High * (night), to measure the effects of flying too much and in nighttime conditions on the likelihood of a mishap.
- High * (overwater flight), to measure the effects of flying too much and in overwater conditions on the likelihood of a mishap
- Low * (night), to measure the effects of flying too few hours and in nighttime conditions on the likelihood of a mishap.
- Low * (overwater flight), to measure the effects of flying too few hours and in overwater conditions on the likelihood of a mishap.

I. SUMMARY

This chapter presented an overview of the data utilized in this thesis and in-depth methodology behind the thesis models. This thesis utilized Stata software (version 14) to create FE logit model for the research. The result from the model allowed the research to examine if there are any key elements that have statistically significant effects on the number of mishaps.

IV. MODEL RESULTS

This chapter presents results from the research models. It also includes discussions on controls and errors found in the data. The controls corrected effects that would have otherwise contaminated the models. In addition, observations with apparent errors found in the data were deleted to maintain consistency with the model estimates. Basic descriptive statistics in Figure 5 and 6 are to help enhance awareness of the trends associated with flight hours and mishap in the study.

A. CONTROLS

FE models account for unobserved variables and control for omitted variable bias (unobserved heterogeneity). The model captures a squadron's regression within itself, allowing these groups to serve as their own control mechanisms for omitted variable bias. In previous studies (Hobbs, 2013; Smith and Brobst, 2010), we see that an increase in the total number of flight hours increases the likelihood of a mishap. Omitted variable bias results from the size of the squadron being different from each other. If one squadron has a larger number of aircraft, then that squadron has the opportunity to fly more. As a result, there is an increase in the number of flight hours, leading to an increase in the probability of mishap.

There is a potential for multicollinearity within the model when there are high correlations among our predictor variables, which can lead to large standard errors of the coefficients. According to Wooldridge (2012), multicollinearity is a concern when the estimated variance inflation factor (VIF) value is greater than 10. Multiple VIF tests were conducted in this research at the individual level and squadron analysis. The tests resulted in VIF less than 10 for all variables. The tests concluded there may be indicators of multicollinearity within the model, but they are too small to warrant further investigation or to have any significant effects on our estimates.

The chronological order of individual and aggregate squadron total daily flight hours has gaps. There are days when a person or squadron does not fly at all. Military career progression rotates individuals out of a squadron on a cycle of three years on

average. As a result, unbalanced panel data served as the data for our models. Wooldridge (2012) suggests that “the mechanics of fixed effects estimation with an unbalanced panel are not more difficult than with a balanced panel” (p. 491). Stata software made appropriate adjustments to the estimates to correct for any unbalanced effects. At the squadron level, date gaps from squadron redesignation or overflow of data from prior years can be attributed to missing dates. Other contributing factors to date gaps were individuals who changed designators, medically discharged, passed away, retired, etc. Those other factors account for a small portion of the model but are worth mentioning.

B. ERRORS

There are more than 1.2 million aggregate individual observations of pilots from the dataset. Of these, 536 showed over 12 total flight hours per day, and six of the observations showed over 24 hours per day. To maintain consistency with NATOPS standards, at 12 hours max flight hours per day, these 536 observations were deleted.

We used Stata software coding to identify duplicate data. The duplicates came after collapsing daily flight hours to form aggregated individual and squadron daily hours and merging them with mishap data. Duplicates were tagged and sorted by individual/squadron and date for manual verification (conserved consistency) before being deleted. Additionally, over 1.2 million observations were coded by frequency of occurrence. Pilots with less than three flights were considered coding error and too small to have any significant effect on the model estimates. The 10,218 observations for these 9,321 pilots were deleted.

C. DESCRIPTIVE STATISTICS

Figure 5 is a frequency distribution bar graph for the total number of annual flight hours between FY00 to FY16. The bar graph in the figure highlights an upward trend in the total number of annual flight hours from FY00 to FY11. It is directly correlated to the Iraq/Afghan active conflict period when military spending was at its peak. There is a decline in the total number of flight hours at the end of FY11 to FY16. Part of this decline is associated with the BCA of 2011 and the sequestration in 2013.

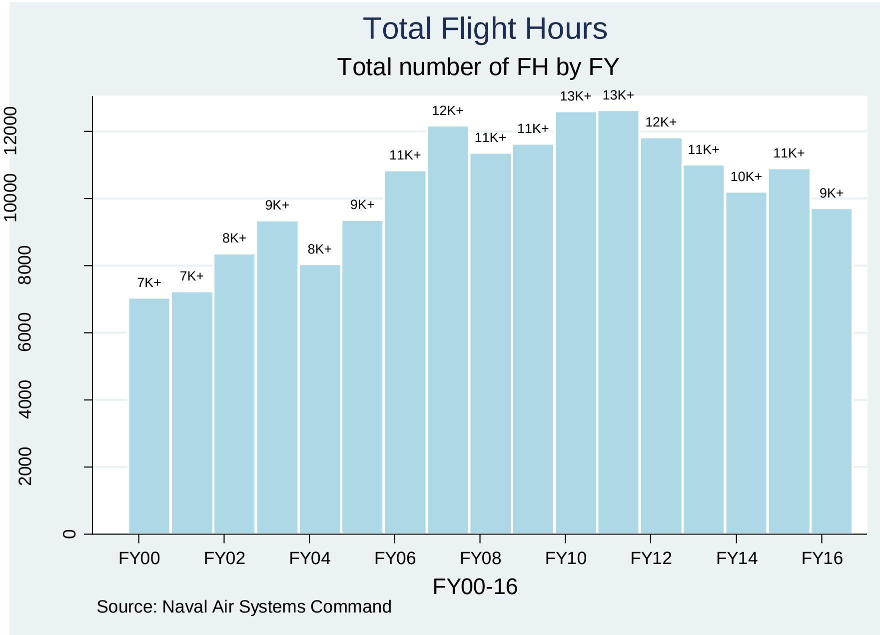


Figure 5. Total Number of Flight Hours FY00–16.

The total number of mishaps in Figure 6 shows an upward trend from FY00 to FY07. A drop in the total number of mishaps appeared in FY08. However, annual total numbers of mishaps continued to trend upward following FY09 to FY16. There was about 253 percent increase in mishaps between FY08 and FY16.

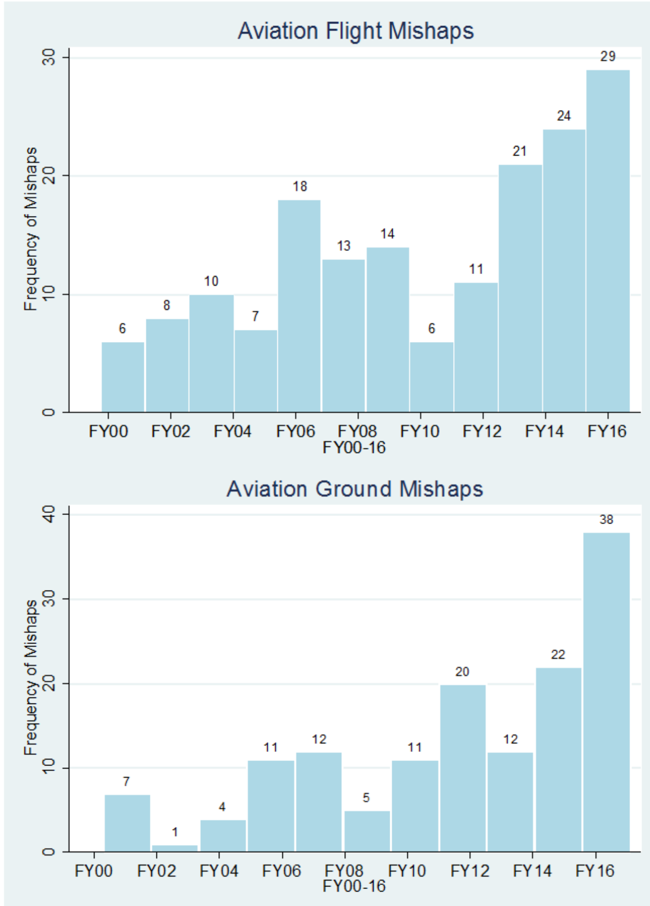


Figure 6. Total Number of Mishaps FY00–16.

D. INDIVIDUAL LEVEL FIXED EFFECTS LOGIT MODELS

There are three logit models based on whether recent flight hours were in the past day, week, or month. These models are in Tables 4–7, and they determined whether the total number of flight hours, sequestration, night flights, or overwater flights are predictive indicators of the likelihood of flight mishaps based on odds ratio. The models in Table 4 represent the estimates at the individual level. The past day, week, and month estimates are based on standardized flight hours.

Table 4. Individual Level Spline and High versus Low Models—Odds Ratio.

Panel A: Spline Model			
	(1)	(2)	(3)
	Flight hours based on past day	Flight hours based on past week	Flight hours based on past month
Sequestration (2013-2016)	**1.08**	**1.07**	**1.04**
	(0.22)	(0.22)	(0.21)
Flight Hours Below Mean	**1.11**	**1.10**	**1.30**
	(0.21)	(0.24)	(0.25)
Whether Flight Hours is Above Mean	**1.17**	**0.89**	**0.73**
	(0.28)	(0.19)	(0.15)
Flight Hours Above Mean	**0.95**	**0.98**	**0.74**
	(0.18)	(0.12)	(0.12)
Night Flights	**1.28***	**1.28***	**1.30***
	(0.16)	(0.16)	(0.16)
Overwater Flight	**0.70****	**0.70****	**0.69****
	(0.09)	(0.09)	(0.09)
N	84075	84075	84075
Panel B: High vs. Low vs. Normal Model			
Mishap (DV)			
Sequestration (2013-2016)	**1.07**	**1.07**	**1.07**
	(0.22)	(0.22)	(0.22)
High Flight Hours	**1.20**	**1.00**	**0.75**
	(0.32)	(0.16)	(0.18)
Low Flight Hours		**0.74**	**0.55**
		(0.26)	(0.22)
Night Flights	**1.28***	**1.28***	**1.27**
	(0.16)	(0.16)	(0.16)
Overwater Flight	**0.70****	**0.70****	**0.69****
	(0.09)	(0.09)	(0.09)
N	84075	84075	84075
The dependent variable is a dichotomous variable.			
Exponentiated coefficients; Standard errors in parentheses.			
*p<0.05, **p<0.01, ***p<0.001			

1. Effects of Sequestration and Flight Hours

The effects of sequestration in panel A and B are near zero and were not statistically significant estimates on the probability of a mishap. Flight hours above the mean in panel A revealed negative associations up to 27 percent for each standard deviation. Flight hours below the mean in panel A have positive associations up to 30 percent. However, both flight hours above and below the mean in panel A show no evidence for an effect. Low hours in panel B are associated with lower probability of a mishap in models 2 and 3 but are not statistically significant. High hours in panel B revealed mixed associations and have no evidence for an effect.

2. Control Variables

Overwater flight in the past day, week, and month in all models from panels A and B are associated with a lower probability of a mishap. The individual estimates are statistically significant (p-value of < 0.01). For an individual, ceteris paribus, the models estimated overwater flights have about 30 percent lower odds of a flight mishap in the previous day, week, and month.

Night flights in all models from panels A and B are associated with a higher probability of a mishap. Night flight in model 3 from panel B shows no effect. The remaining models show statistically significant estimates for night flights (p-value < 0.05). For an individual, ceteris paribus, with the exception of model 3 from panel b, night flight had about 30 percent higher odds of a flight mishap in the previous day, week, and month.

3. Summary

These estimates suggest that at the individual level analysis, there is not enough evidence to support the hypothesis that causal factors for the likelihood of a mishap were from flight hours above or below the mean and sequestration. Additionally, there is not enough evidence to support the hypothesis that low standardized flight hours in the bottom 10th percentile and high hours in the 95th percentile were causal factors to the likelihood of a mishap.

E. SQUADRON LEVEL FIXED EFFECTS LOGIT MODELS

The models in Table 5 represent the estimates at the squadron level. The previous day, week, and month estimates were based on standardized flight hours by individual squadron.

Table 5. Squadron Level Spline and High versus Low Models—Odds Ratio.

Panel A: Spline Model			
	(1)	(2)	(3)
	Flight hours based on past day	Flight hours based on past week	Flight hours based on past month
Sequestration (2013-2016)	**1.78****	**1.80*****	**1.83*****
	(0.31)	(0.32)	(0.32)
Flight Hours Below Mean	**0.92**	**1.15**	**0.87**
	(0.16)	(0.24)	(0.15)
Whether Flight Hours is Above Mean	**1.16**	**0.99**	**0.82**
	(0.22)	(0.22)	(0.19)
Flight Hours Above Mean	**1.28***	**1.11**	**1.18**
	(0.14)	(0.13)	(0.16)
Night Flights	**0.89**	**0.91**	**0.94**
	(0.13)	(0.14)	(0.14)
Overwater Flight	**1.76****	**1.79****	**1.83****
	(0.34)	(0.35)	(0.36)
N	110315	110315	110315
Panel B: High vs. Low vs. Normal Model			
Mishap (DV)			
Sequestration (2013-2016)	**1.79*****	**1.81*****	**1.82*****
	(0.32)	(0.32)	(0.32)
High Flight Hours	**2.30*****	**1.12**	**1.04**
	(0.46)	(0.29)	(0.28)
Low Flight Hours		**0.59**	**1.22**
		(0.17)	(0.26)
Night Flights	**0.91**	**0.92**	**0.94**
	(0.14)	(0.14)	(0.14)
Overwater Flight	**1.78****	**1.80****	**1.82****
	(0.35)	(0.35)	(0.35)
N	110315	110315	110315
The dependent variable is a dichotomous variable.			
Exponentiated coefficients; Standard errors in parentheses.			
*p<0.05, ** p<0.01, *** p<0.001			

1. Effects of Sequestration and Flight Hours

The models in Table 5 are created based on the conjecture that total flight hours is used as an indicator to squadron OPTEMPO from Hobb's research (Hobbs, 2013). Only with that assessment, we can estimate the effect of total flight hours on the likelihood of a squadron mishap with the following analysis.

Sequestration in all models from panels A and B are associated with a higher probability of a mishap (p-value of about < 0.001). Ceteris paribus, the model estimated

about 80 percent higher odds of a mishap if flights are flown during periods of sequestration in the previous day, week, and month.

Flight hours above the mean in the previous day in model 1, panel A are associated with a higher probability of a mishap (p-value < 0.05). Ceteris paribus, the model estimates for every unit increased in the standard deviation of flight hours above the mean in the previous day, there is 28 percent increased odds of a mishap. The remaining flight hours estimate above and below the mean in panel A have mixed association, and there is no evidence of an effect.

High hours in the previous day in model 1, panel B are associated with a higher probability of a mishap (p-value < .001). Ceteris paribus, the model estimates for every unit increased in the standard deviation of flight hours at the 95th percentile in the previous day, there are 130 percent greater odds of a mishap. High hours in the previous seven and 30 days have positive association up to 12 percent, but there no evidence for an effect. Low hours in panel B have mixed association, and there is no evidence of an effect.

2. Control Variables

Overwater flight in the past day, week, and month in all models from Panel A and B are associated with a higher probability of a mishap. The individual estimates are statistically significant (p-value of < 0.01). For overwater flight, ceteris paribus, the models estimate about 80 percent higher odds of a flight mishap when the squadron is operating missions over water in the previous day, week, and month.

Night flights in all models from panels A and B are associated with a lower probability of a mishap. The models estimate near 10 percent lower odds of flight mishap when the squadron operates missions at night; however, there is no evidence of an effect.

3. Summary

These estimates suggest that at the squadron level analysis, there is not enough evidence to support the hypothesis that causal factors for the likelihood of a mishap were from low or below the mean flight hours. Additionally, there is not enough evidence to

support the hypothesis that night flight for a squadron were causal factors to the likelihood of a mishap.

F. SPLINE INDIVIDUAL AND SQUADRON INTERACTION MODELS

The models in Table 6 provide estimates on the likelihood of a mishap using standardized flight hours within the previous week at the squadron and individual levels. The models include interactions to estimate conditions of flights. In addition, the models in Table 6 are a sample of the weekly estimate of interaction variables. The previous day and month standardized flight hour models show no statistically significant estimates and are not included.

Table 6. Individual and Squadron Spline Interaction Models.

Panel A: High vs. Low vs. Normal Interactions Model		
	(1)	(2)
	Flight hours based on past week for a squadron	Flight hours based on past week for an individual
Sequestration	**1.81*****	**1.07**
	(0.32)	(0.22)
Low Flight Hours	**1.09**	**0.88**
	(0.57)	(0.22)
High Flight Hours	**0.62**	**0.98**
	(0.67)	(0.50)
Low Flight Hours and at Night	**1.25**	**0.73**
	(0.78)	(0.24)
High Flight hours and at Night	**1.08**	**0.48**
	(0.73)	(0.35)
Low Flight hours and Overwater Flight	**0.36**	**1.66**
	(0.23)	(0.52)
High Flight hours and Overwater Flight	**1.78**	**1.05**
	(1.92)	(0.73)
Night Flights	**0.90**	**1.39***
	(0.14)	(0.19)
Overwater Flight	**1.92****	**0.63****
	(0.41)	(0.09)
N	110315	84075
The dependent variable is a dichotomous variable.		
Exponentiated coefficients; Standard errors in parentheses		
*p<0.05, ** p<0.01 , *** p<0.001		

1. Effects of Sequestration and Flight Hours

The period of sequestration in both models 1 and 2 are associated with a higher probability of a mishap. However, sequestration is only statistically significant at the squadron level (p-value < 0.001). For sequestration estimates, ceteris paribus, the model revealed at the squadron level 81 percent higher odds of a mishap if flights are flown during periods of sequestration in the previous week.

Low and high flight hours in both models 1 and 2 have mixed association, and there is no evidence of an effect. Low and high hours at night show mixed associations in both models, but there is no evidence of an effect. Additionally, low and high hours flown over water have mixed association, and there is no evidence of an effect.

2. Control Variables

There is an opposite effect of overwater flight between the individual level and squadron level estimates. Overwater flights in the previous week are associated with a 92 percent higher probability of a mishap at the squadron level and a 37 percent lower probability of a mishap at the individual level. The models are statistically significant (p-value of < 0.01). For a squadron that conducted flights over water, ceteris paribus, the models estimate about 92 percent higher odds of a flight mishap in the previous week. For an individual who had a flight over water, ceteris paribus, the models estimate about 37 percent lower odds of a flight mishap in the previous week.

There is an opposite effect of night flight between the estimates at the individual and squadron levels. Night flight for a squadron in the previous week are associated with a lower probability of a mishap, and there is no evidence of an effect. Night flight for an individual are associated with 39 percent higher probability of a mishap and is statistically significant (p-value < 0.05). For an individual, ceteris paribus, the models estimated night flight to have 39 percent higher odds of a flight mishap in the previous week.

3. Summary

These estimates suggest that for a squadron or an individual, there are no evidence for too much or too few hours having an extra effect for night or overwater flights in the previous week.

G. MISHAP COMPARATIVE MONTHLY MODELS

The models in Table 7 represent comparative mishap estimates at the squadron level based on standardized flight hours from the previous month.

Table 7. Monthly Squadron Mishap Comparison Models.

Panel A: High vs. Low vs. Normal Squadron Comparison Models			
	(1)	(2)	(3)
	Flight/Ground	Ground	Flight
	Mishap	Mishap	Mishap
	In Past Month	In Past Month	In Past Month
Sequestration	**1.83*** **	**1.81*** **	**1.42**
	(0.32)	(0.41)	(0.34)
High Flight Hours	**1.04**	**0.91**	**1.00**
	(0.28)	(0.35)	(0.37)
Low Flight Hours	**1.22**	**1.71***	**1.50**
	(0.26)	(0.42)	(0.39)
Night Flights	**0.94**		**0.92**
	(0.14)		(0.18)
Overwater Flight	**1.82****		**1.61**
	(0.35)		(0.39)
N	110315	98356	105194
The dependent variable is a dichotomous variable.			
Exponentiated coefficients; Standard errors in parentheses.			
*p<0.05, ** p<0.01, *** p<0.001			

1. Sample Ground Maintenance Mishap

The combined mishap and ground mishap models in Table 7 are only a concept to show how an estimation of flight hours as an indicator for squadron OPTEMPO could affect the likelihood of maintenance related mishaps. To estimate the true effect of total number of flight hours on the likelihood of a ground mishap, the models would need to be based on all possible days of maintenance or maintenance hours. This models is an example of how it could be calculated without accounting for all possible days of

maintenance and does not reflect the true effects of ground mishaps based of the total number of flight hours.

2. Effects of Sequestration and Flight Hours

Sequestration in model 1 in Table 7 reveal positive associations regarding the likelihood of a mishap. However, sequestration is only statistically significant for combined mishap and ground mishap (p-value < 0.001). For combined mishap and ground during the period of sequestration, ceteris paribus, a squadron has 83 percent higher odds of a combined mishap and 81 percent higher odds of a ground in the previous month.

Low flight hours in the previous month in model 2, panel A are associated with a lower probability of a ground mishap (p-value < 0.05). Ceteris paribus, the model estimates for every unit decreased in the standard deviation of flight hours below the mean in the bottom 10th percentile, there is 71 percent decreased odds of a ground mishap in the previous month. The remaining high and low flight hours in Table 7 had mixed association; however, there is no evidence of an effect on the remaining models.

3. Control Variables

Overwater flight in models 1 and 3 for the previous month are associated with a higher probability of a combined mishap and flight mishap. There are statistically significant estimates for combined mishaps (p-value < 0.01). Overwater flight and night estimates do not have associations with a ground mishap and are not included in model 2. Ceteris paribus, the models estimate 82 percent higher odds of a combined mishap when the squadron is operating missions over water in the previous month.

Overwater estimates are associated with a higher probability of a flight mishap, but show no evidence of an effect. Night flights in models 1 and 3 are associated with a lower probability of a combined or flight mishap but show no evidence of an effect.

4. Summary

These estimates suggest that for a squadron, there is no evidence for too much or too few hours having an effect on combined, ground, and flight mishaps in the previous month.

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V. CONCLUSION

This research examined the relationship between mishaps and flight hours using historical panel data. Specifically, it provided analysis with controls for night flight and overwater. The models estimated effects on the likelihood of mishaps using standardized flight hours from the past day, week, and month. Low and high flight hours were used as indicators to estimate fatigue and low levels of proficiency. Furthermore, a dichotomous variable sequestration was created to estimate the effects of mishaps during that period.

Previous research examined the effect of mishap and flight hours on fixed winged naval aviation (Hobbs, Smith and Brobst, Brobst et al., 2013, 2010, 2016). Hobbs' (2013) study compared mishap rates based on identifying periods of low flight hours. Smith and Brobst (2010) analyzed the effects of reduced training on proficiency levels. Brobst et al. (2006) examined the relationship between safety and proficiency. The models for this research, on the other hand, provided an econometric statistical approach to analyzing the relationship between the likelihood of mishaps and the total number of flight hours.

Statistics from our historical data showed that when flight hours increased from FY00 to FY07, the total number of mishaps increased. However, from FY09 to FY16, the total number of flight hours decreased, and the total number of mishaps increased substantially. The reduction in the total number of flight hours that resulted in an increased in the number of mishaps could be attributed to levels of low levels proficiency or complacency. This aligns with the findings of Smith and Brobst (2010) that low recent flight hours were linked to increased numbers of mishaps. Conversely, Smith and Brobst (2010) also found that complacency from flying too often in times of active conflict might be a contributing factor to the increased likelihood of a mishap. Reduced levels of proficiency arise from not having enough flight hours to train. Over time, memory degrades, leading to decreased situational awareness from not flying often and increasing the likelihood of mishaps.

The effect on the likelihood of mishaps during a period of sequestration for a squadron, compared to the individual, is more prominent in the models. They revealed

periods of sequestration had a more statistically significant impact on a squadron than on an individual. At the individual level, the total number of flight hours required to maintain proficiency varies from one person to the next. Each pilot takes a smaller cut to his or her total flight hours when a squadron loses funding for the total number of flight hours. As a result, the effects of mishaps from sequestration have less of an effect on the individual than the squadron. The squadron has to distribute the reduction in the total number of flight hours evenly between all of its pilots. The cumulative effects of sequestration are more prevalent to the squadron as a result, and this includes cumulative numbers of mishaps and changes in the OPTEMPO.

At the squadron level, every one unit increased in the standard deviation of flight hours flown above the mean in the previous day increases the odds of having a mishap by 1.3. Additionally, every one unit increased in the standard deviation of flight hours flown above the 95th percentile in the previous day increases the odds of having a mishap by 2.3. The estimate indicates that flights above the mean hours and above the 95th percentile in the previous day had a stronger impact on the squadron than cumulative hours in the previous week and month. There was no statistically significant evidence to estimate that hours flown in the previous week and month affected the likelihood of a mishap.

At the squadron level, every unit decreased in the standard deviation of flight hours below the mean in the bottom 10th percentile, there is 71 percent decreased odds of a ground mishap in the previous month. Low flight hours lead to reduced work requirement for maintenance personnel. As a result, the maintenance hours required for these evolutions are minimal compared to other maintenance related functions and leads to a reduction in the likelihood of a ground mishap.

The research model estimates show that the total number of standardized flight hours had no statistically significant effects on the likelihood of having a mishap for an individual pilot. However, at the individual level, night flights over the period of a week and month increases the odds of having a mishap. Nighttime flying reduces situational awareness, increases fatigue, and disrupts circadian rhythm. The individual estimates showed that over time, those factors had higher influenced on the likelihood of a mishap.

The model suggests that cumulative night flights over a period of a week or a month lead to higher likelihood of having a mishap.

At the individual level, a pilot who flew over water TMR coded missions for a period of seven or more days had lower odds of having a flight mishap. The main contributing factor is proficiency in overwater flying and training. Naval aviators fly most missions over water, which helps in sustaining proficiency levels on consistent intervals. The overland missions such as personnel recovery and special operations forces are considered secondary to SAR for the helicopter community and almost nonexistent for MH-60R pilots.

Finally, the effects of sequestration are more prevalent at the squadron level than at the individual level. A reduction in the budget affects the vast number of operational requirements of a squadron that each must select. These issues include a revised training syllabus, division of flight hours, acquiring parts for maintenance, shortage of required maintenance personnel, and so forth. With the exception of flight mishaps alone, the estimates showed the period of sequestration to be statistically significant on all squadron level models. This finding does not prove sequestration to be the cause for the increased the likelihood of a mishap but it is an indicator that the periods of sequestration had an effect on the likelihood of mishaps. Combined with previous studies, this suggests strong evidence and warrants additional consideration about budgetary funding of naval aviation.

Further research is suggested regarding the relationship between flight mishaps and the total number of flight hours using similar models in this thesis to provide more information on the effect of sequestration on flight mishaps. Analyses with different aircraft platforms would provide more data to better observe trends dealing with flying too many or too few hours, sequestration, the reduction in the total number of flight hours and the likelihood of mishaps. Additionally, future models of ground mishaps must account for all possible days of maintenance or maintenance hours. This research did not have all the resources required to models those affect.

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